PROGRESS TOWARDS MORE UNIFORM ASSESSMENT AND REPORTING OF SOIL DISTURBANCE FOR OPERATIONS, RESEARCH, AND SUSTAINABILITY PROTOCOLS

Michael P. Curran[a1], Richard E. Miller[b], Steven W. Howes[c], Douglas G. Maynard[d], Thomas A. Terry[e], Ronald L. Heninger[f], Thomas Niemann[g], Ken Van Rees[h], Robert F. Powers[i], and Stephen H. Schoenholtz[j],

[1]Corresponding author, [a]B.C. Ministry of Forests, Forest Sciences Program, Kootenay Lake Forestry Centre, 1907 Ridgewood Rd., Nelson B.C., Canada, V1L 6K1. (also Adjunct Professor, Agroecology, University of B.C.). Phone: 250-825-1100. E-mail: mike.curran@gems5.gov.bc.ca;
[b]Emeritus Scientist, Pacific Northwest Research Station, Forestry Sciences Laboratory, 3625, 93rd Avenue S.W., Olympia, WA 98512-9193
[c]USDA Forest Service - Pacific Northwest Region P.O. Box 3623, Portland, OR 97208-3623
[d]Natural Resources Canada, Canadian Forest Service, 506 West Burnside, Victoria, B.C., Canada, V8Z 1M5.
[e]Weyerhaeuser Company, Box 420, Centralia, WA, USA. 98531
[f]Weyerhaeuser Company, P.O. Box 275, Springfield, OR, USA. 97478-5781
[g]B.C. Ministry of Forests, Forest Practices Branch, P.O. Box 9513, Stn.Prov.Govt., Victoria, B.C., Canada. V8W 9C2
[h]Department of Soil Science, 51 Campus Drive, University of Saskatchewan, Saskatoon, SK, Canada S7N 5A8
[i]USDA Forest Service, Pacific Southwest Research Station, 2400 Washington Ave., Redding, CA. 96001
[j]Department of Forest Engineering, Oregon State University, 267 Peavy Hall, Corvallis, OR 97331-5706

Abstract

International protocols, such as those of the Montreal Process (MP), specify desired outcomes without specifying the process and components required to attain those outcomes. We suggest that the process and its components are critical to achieve desired outcomes. We discuss recent progress in northwestern North America, on three topics that will facilitate development of and reporting in sustainability protocols: (1) common terms and comparable guidelines for soil disturbance, (2) cost-effective and statistically sound techniques for monitoring and assessing soil disturbance, and (3) improved methods to rate soils for risk of detrimental soil disturbance. Uniform terms for soil disturbance will facilitate reporting and exchange of information. Reliable monitoring techniques and tracking the consequences of soil disturbance for forest growth and hydrology are paramount for improving understanding and predictions of the practical consequences of forest practices. To track consequences, we urge creation of regional research and operations databases that can be used to: (1) address MP values, (2) define detrimental soil disturbances, (3) develop risk-rating systems for operational application, and (4) improve best management practices (BMPs) and ameliorative treatments that avoid or correct detrimental disturbances.

Keywords: Soil compaction; Rutting; Monitoring; Adaptive management; Criteria and indicators; Montréal Process

Introduction

Sustainable management of forests requires maintenance of the soil resource including its biological, chemical and physical properties and processes. This dependency is addressed at many levels (scales): at a local and regional level through operational guidelines and standards, and more recently at national and international levels through sustainability protocols (e.g., Criteria and Indicators of the Montreal Process) and third-party certification.

The Montreal Process (MP) included a Working Group on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests (Montreal Process Working Group 1997). The MP is supported by 12 non-European countries covering five continents and representing 90% of the world's temperate and boreal forests. A major purpose of the Montreal Process, and the similar Pan European (formerly the Helsinki Agreement), is to provide a common framework for describing, assessing, and evaluating each member country's progress towards forest sustainability. Indicators will be used to describe, assess and evaluate progress. Two of the indicators for the conservation and maintenance of soil and water resources refer to area and percent of forestland with significantly diminished soil organic matter (indicator 21) or significant compaction (indicator 22). Clearly, we need to define what is significant. Moreover, we need to validate an underlying assumption that we know what amount of organic matter loss or severity of compaction will lower forest productivity, and where and to what extent.

The MP clearly identifies indicators 21 and 22 as "b-type" indicators, which "may require the gathering of new or additional data and/or a new program of systematic sampling or basic research". Yet, some nations, including the USA, are monitoring or sampling compaction before "significant" changes in compaction levels have been reliably defined or validated.

In the USA, the current response to the MP for federal forestland is to utilize the existing systematic grid of forest inventory plots as the sampling matrix, then estimate extent of compaction at these sample locations. Responsibility for responding to the MP and to the larger Forest Health issue has largely been assigned to the USFS Forest Inventory and Assessment Group (FIA). To help guide this large effort, we strongly recommend soil scientists participate in

the processes and review results reported to the Montreal Process by Technical Advisory Committees (TACs) and the FIA. Of highest priority, is to quantify the practical consequences of changes in soil physical properties and soil organic matter that are important for sustainable forestry.

One approach to addressing "b-type indicators" is to use locally applicable "standards" as proxies and then ensure adequate validation occurs to confirm that existing "guidelines and standards" adequately address the intent of the indicator. This is the process adopted by the Canadian Council of Forest Ministers' in their criteria and indicators for sustainable forest management (CCFM 1999, 2003). Compliance with locally applicable guidelines could also be a proxy for these MP indicators. Commensurate with use of guidelines and standards as proxies is the paramount need to test and adapt these guidelines and standards in a reliable continual improvement (adaptive management) framework.

No clear linkages have been established between changes in specific soil properties and productivity or sustainability. Therefore, what valid inferences or conclusions can be drawn from a national inventory of the status of soil properties in forested areas as proposed by the Montreal Process? How could inferences from such inventory data improve sustainable forestry? We suggest a more promising approach is to: (a) inventory the percentage of forested land that is controlled by other legislative or voluntary processes, such as state or provincial forestry practice codes, Sustainable Forestry Initiative (American Forest and Paper Association), Canadian Standards Association, Forest Stewardship Council, ISO 1400.1, and federal legislation (National Forest Management Act of 1976 and National Environmental Policy Act of 1969); and (b) ensure that regional databases are developed to document severities of soil disturbance that are detrimental to forest productivity across the range of soils and conditions where production forestry is practiced. Existing codes, legislative acts, and voluntary agreements have documented procedures, standards, and guidelines for protecting and maintaining forest productivity. Most also seek continual improvement of process guideline and standards. Regional databases should provide the information from which detrimental soil disturbances can be defined. Best

management practices (BMPs) and ameliorative treatments can subsequently be prescribed to avoid or correct disturbances that are deemed detrimental.

The Montreal Process indicates some desired outcomes (indicators) without describing the processes to achieve them. Presumably, individual countries will decide the process. We believe the adaptive management process (continuous improvement) that is used to achieve sustainability is more important than MP indicators. Further, by employing common terminology, definitions, and approaches we can reduce the burden of demonstrating sustainability, while ensuring that sustainably is implemented into practice.

Progress towards a common approach starts at the regional level. While most organizations have different approaches and priorities, many have similar settings and environmental issues. Therefore, it is appropriate to coordinate and cooperate on issues of sustainability. Within a region, issues include BMPs, tools, and databases, in which research results are tracked, summarized, and put into context for successful application.

In this paper, we discuss recent "regional" progress in northwestern North America, on three topics that will facilitate reporting under various sustainability protocols:

A. Common terms and comparable guidelines for soil disturbance,

B. Cost-effective and statistically sound techniques for assessing and monitoring soil disturbance, and

C. Reliable methods to rate soils for risk of detrimental soil disturbance.

Section A. Common Terms and Comparable Standards for Soil Disturbance

Reliable reporting and comparing soil disturbance require agreement about terms. Unambiguous terms and definitions will increase utility of operational and research data, and improve transfer of data and experience for reports and data synthesis. Common terms are needed both for describing physical disturbance and for describing the practical application of this

information. When physical properties like bulk density and porosity are reported, we need to know what is being described and how it was determined. For example, was bulk density that of the total soil or of the fine-fraction? We also need to use similar approaches to measure and describe confounding factors, such as vegetative competition. Terms like "compacted", "sensitive", "rutted", and, "disturbed" need common definitions.

Current Status, And What Is Needed

Several classification systems exist for characterizing soil disturbance, but few have the same definitions of disturbance types or classes. These differences in definition affect guidelines and standards for controlling soil disturbance, which should be comparable, particularly at the regional level. We assert that more consistent terminology in defining soil disturbance would result in: (1) improved communication among various stakeholders of the forest resource, (2) better alignment of guidelines and standards, (3) more clearly focused research to assess the effect of soil disturbance on forest productivity and ecosystem function, and (4) more effective monitoring systems to quantify levels and effects of soil disturbance.

Ease of communication can be improved through the use of common classification systems and language. Improved communication will provide the various stakeholders (e.g., managers, loggers, public) with the information they need to understand and decide. Common definitions of disturbance also will enable comparing and learning across ownerships and legal boundaries. Most importantly, commonality of terms may increase the awareness of the public with respect to the issue of soil conservation and its relevance to sustainability (Salafsky and Margoluis 2003).

Desired criteria for developing consistent soil disturbance classes include: (1) disturbance types are primarily defined by visual (morphologic) attributes rather than quantitative physical properties, (2) disturbance types are easy to communicate, and (3) disturbance types are correlated with soil variables that affect tree growth and hydrological or ecological function.

Classification systems that meet these criteria have been successfully used by the B.C. Ministry of Forests (Forest Practices Code Act 1995) and Weyerhaeuser Company (Scott 2000), and are currently under developmental use in the USFS Region 6 (Pacific Northwest). In addition to meeting the three criteria outlined above, the classification systems are successfully combined in monitoring protocols to determine severity and areal extent of soil disturbance after operational harvesting (B.C. Ministry of Forests 2001, Heninger et al. 2002).

The advantage of a visual classification system compared to a quantitative measurement (e.g., bulk density) is that monitoring is less time-consuming and easier to measure on a routine basis. However, one concern of a visual classification system is ensuring the consistency and repeatability of disturbance classification among classifiers.

It is imperative that the disturbance classification system is validated with response variables that are ecologically relevant, such as tree growth or survival, which are direct evidence of change in the site's capacity to grow vegetation. Two examples follow:

(1) Douglas-fir seedlings can tolerate saturated conditions for about 10 days before dying (Minore 1968). Saturated areas can be created when harvesting equipment affects above-or below-ground water movement. This Class 5 disturbance (Scott 2000) results in unfavorable planting spots for Douglas-fir seedlings.

(2)Replicated field studies demonstrated that a similar severity of soil disturbance can have different effects on Douglas-fir seedling growth, depending on the soil and climate zone where disturbance occurred. In the coastal Spruce zone of western Washington, no difference in 7-to-8 year height and volume existed between Douglas-fir planted directly into the skid-trail tracks (mostly class 2 disturbance; puddled topsoil) and trees planted off trails (Miller et al. 1996). Yet in a drier growing season climate (near Springfield, Oregon) and soils with higher clay and lower organic matter content , 10-year-old trees originally planted in a similar soil disturbance class (class 2 disturbance, skid-trail tracks) averaged 0.6 m (10 percent) shorter and less volume than trees on logged-only or tilled skid trails (Heninger et al. 2002).

Using a consistent method for classifying harvest-related disturbance across a gradient of soil and climate conditions is highly desireable, especially when combined with a database that

documents tree response. Such databases can be expanded and updated to provide longer term validation of growth trends. Consistent criteria that should be considered include categories of permanent and temporary access. Permanent access is the main road network that will not be reforested and temporary access includes in-block disturbance like logging trails that will be reforested.

Classification criteria, or the interpretation of various classes, will change as more response data become available. For example, the Weyerhaeuser system for soil disturbance classification in the Pacific Northwest could be improved by incorporating additional classes or subclasses to describe the lateral width of disturbance, similar to the topsoil displacement categories used in the B.C. system. The Weyerhaeuser and B.C. Min. Forests disturbance types are described in more detail in tables and figures in Curran et al. (200x).

Narrow areas of a given disturbance type may be inconsequential to future wood yield, if seedlings can be planted at a nominal spacing outside the disturbed area. To maintain uniform seedling spacing in wide areas of disturbance, however, seedlings are usually planted within the disturbance and a much larger part of the rooting zone will be affected. Seedling performance is more likely to be affected. Additional studies are needed to ascertain seedling performance across such a gradient of increasing area of specified disturbance classes. The Long Term Soil Productivity (LTSP) studies anchor the extreme end of this width gradient by planting seedlings where 100% of the area was compacted (Powers et al. 1990). These geographically extensive LTSP studies will continue to make important contributions to a database relating width of a compacted area and long-term effects on tree growth. Moreover, technical communication among LTSP cooperators enhances benefits among this peer group from agencies, universities, and industry.

Progress

Indicative of progress is the willingness of professionals to work as a group to address current issues. Soil scientists in the Pacific Northwest, for example, have initiated

peer-networking within a Soil Disturbance Working Group of the Northwest Forest Soils Council. In Canada, a National Forest Soil Disturbance Working Group is forming. Similarly, national-level interest is apparent in the USA. Although progress has been temporarily delayed due to a number of factors, including the wildfires of 2003, the groups are committed to progressing on the following interim products:

- Compare current visual disturbance classes. Contrast and correlate visual disturbance classes by expanding tables developed by Ken Van Rees for Weyerhaeuser in Saskatchewan.
- Correlate and assess absolute and relative measures of compaction and related physical properties (bulk density, porosity measures, least limiting water range (LLWR), penetration resistance and other measures of soil strength.
- Relate tree growth and visual criteria of disturbance. We infer from the present literature that we should not generalize about these relationships. For example, where the practical consequences of compaction for tree performance have been measured, growth has been decreased (Curran and Maynard 2000x), decreased for a limited period (Heninger et al. 2002), been unaffected (Miller et al. 1996), or been increased (Powers and Fiddler 1997, Brais 2001). For northern California, Gomez et al. (2002) reported that seedling response varied from negative to positive, depending on soil texture. In short, soil physical properties were changed, but the consequences for sustainable forestry ranged between positive to negative, depending on the soil and climatic situation. Such information should be tracked in a strategic database that documents types and severity of disturbance that actually affect site productivity or hydrology. Continuing documentation and periodic analysis are required to elucidate trends and change policy and practices.
- Revise guidelines and standards for soil disturbance. Including which types of disturbance should be "Counted", as discussed by Curran et al. (2000x). A number of draft tables have been completed by Ken Van Rees for Weyerhaeuser in Saskatchewan, and we intend to complete these for both Canada and the USA.

Recommendations

- Secure greater support from our collective agencies, so all can achieve the benefits of consensus about terms and methods.
- Common classification criteria are needed to facilitate a common approach (e.g., categories of permanent access versus "in-block disturbance" temporary access like ruts, bladed trails, compaction, and displacement of topsoil).
- Recognize that disturbance classification is not the final end product. Having reliable monitoring techniques, and more importantly tracking the consequences of soil disturbance for forest growth and hydrology are paramount to improving understanding and prediction of the practical consequences of forest practices. Classification is a tool to facilitate consistent communication of this knowledge.
- Set criteria for deciding when a given disturbance type is "counted" or considered "detrimental." This is further discussed in Section B (monitoring) and Section C (risk-rating).

Section B. Cost-effective techniques for monitoring and assessing soil disturbance.

Current status, and what is needed

Numerous methods exist for assessing or sampling soil disturbance in both operational and research settings. Methods differ with respect to sampling objectives, soil variables considered, and assessment protocols. Inconsistent application of soil disturbance measurement techniques across a variety of land ownerships has led, in some cases, to unreliable and incomparable results. More effective and efficient (of cost and utility of data) soil disturbance monitoring and assessment programs could be achieved through use of common soil-disturbance classes and consistent use of statistically reliable sampling protocols.

Monitoring can be as simple as determining if specified soil conservation or best management practices (BMP) have been implemented as planned or if contractual/legal requirements relating to soil disturbance have been met. This is often referred to as *compliance* or *implementation* monitoring (e.g., Were skid trails designated in advance and properly spaced?).

Soil disturbance monitoring is usually done to evaluate effectiveness of management practices in meeting pre-determined, usually provisional soil disturbance standards based on best available knowledge. This is commonly referred to as *operational* or *effectiveness* monitoring (e.g., Was implementation of a specified suite of BMPs effective in meeting soil disturbance standards or soil management objectives?).

Soil disturbance standards or objectives must be tested or validated to determine if they are appropriate for local site conditions or if adjustments are needed. This process is usually referred to as *validation* monitoring. Validation is best accomplished in a research environment with controlled conditions. Contrary to the current situation in nearly all organizations, the research should be completed before standards are developed and implemented. Meaningful soil disturbance standards or objectives should eventually be based on measured and documented relationships between severity of disturbance and subsequent tree growth, forage yield, or hydrologic response. Studies designed to determine these relationships are generally carried out as part of controlled and replicated research projects.

Cost-effective approaches are needed for operational soil disturbance assessments or monitoring that provides statistically valid and scientifically relevant data. To be cost-effective, soil disturbance monitoring protocols must meet several criteria. Protocols: (1) must provide scientifically and technically sound information, (2) must be reliable, pertinent and obtained with minimum investments, (3) must be clearly communicated and understood by all parties affected, and (4) must be consistently and efficiently implemented. Each of these criteria will be discussed to clarify its importance.

1. *Scientifically and technically sound.* - Monitoring or assessment protocols must be statistically valid so that objective, reproducible conclusions can be made about the occurrence

and distribution of soil disturbance across the harvested area. Sampling rules must be clearly specified and designed to obtain representative and unbiased samples. Monitoring must meet specified quality-control standards and contribute to regional strategic databases about soil responses (to support tree growth, hydrologic function) to defined classes of disturbance.

2. *Reliable, pertinent, information obtained with minimum investments.* - Protocols must be operationally feasible and fit within budgetary constraints. Disturbance monitoring programs can be expensive, time-consuming, and cost-prohibitive if not planned properly. Limited monitoring dollars must be spent wisely. Soil disturbance monitoring and assessment efforts should be stratified so that sampling is most intensive on areas with high risk of soil disturbance impacts due either to timing of operations (wet soils) or to the inherent vulnerability or risk of the soil to be negatively impacted.

3. *Clearly communicated and understood by all affected parties.*- Consistent communication and interpretation of information is important when comparing protocols, sharing operational monitoring information, and reporting progress relative to meeting international protocols for achieving soil sustainability. A common approach to describing disturbance types is promoted by the authors (section A); effective communication of this information within and among agencies, companies, and the public is important.

4. *Consistently and effectively implemented.*- Deviations from a specified protocol and difference in observers' bias can strongly affect monitoring results. To secure reliable monitoring data, monitors must receive rigorous initial and subsequent training. Quality control is necessary to ensure reliable data.

Progress

Validation.- Nationwide, the USDA Forest Service has established threshold standards for detrimental soil disturbance similar to those established for the Pacific Northwest Region (FSM 2520.R6 Supplement No. 2500.98.1 effective August 21, 1998) and the California Region (FSH

2509.18-95-1, effective 6/11/95). For example, within the operational area (defined as 100 percent of that portion devoted to growing vegetation):

- Erosion (may not exceed the estimated rate of soil formation, e.g., 2 Mg ha^{-1} yr^{-1}),
- Ground cover (must protect at least 50 percent of area immediately after an activity),
- Coarse woody debris (retain > 5 large logs ha^{-1}, 20 inches (50.8 cm) diameter X 10 feet (3.05 m) in length and in various decay classes).
- Infiltration (avoid erosion hazard rating of 6 or 8, R5-FSH-2509.22, ch. 50)
- Soil compaction (reduce total porosity <10 percent)
- Soil displacement (retain organic matter content in upper 30 cm within 15 percent of natural)

These provisional soil-based standards set thresholds beyond which a soil's productive capacity may be seriously impaired (e.g., a loss in potential productivity of at least 15 percent) (Figure 1).

But the paucity of validating research means that such standards are based largely on professional judgment and can be challenged as being too restrictive, not restrictive enough, or insensitive to particular soil or site conditions. For example, soil compaction is generally considered detrimental to tree growth (Froehlich and McNabb 1984). Yet, Gomez et al. (2002) found on droughty sites that soil bulk density increases of 20 percent or more (0- to 30-cm depth) impaired tree growth on a fine-textured clayey soil, had a benign effect on a loam, but enhanced growth on a coarse-textured sand.

Responding to the need to validate existing standards and to refine the concept in Figure 1, a national program of Long-Term Soil Productivity (LTSP) research was established in 1989 (Powers et. al. 1990). LTSP applies a standard template of soil compaction and organic matter removal treatments to a broad range of sites where physical, chemical, and biological indices of soil quality are compared against tree growth. Canadian partners in the LTSP, such as the B.C. Ministry of Forests, are also using the LTSP protocol as part of the validation process for their local soil disturbance standards. Presumably, a change in tree growth caused by treatment will correspond to a change in a soil variable useful in monitoring. A pilot program in California is validating established soil quality standards (stated earlier) against measured growth on older

LTSP experiments across a range of soil textures. Ideally, each region should have adequate field studies to set or validate threshold values for soil variables after individual activities, and after various likely combinations (to assess cumulative effects).

Compliance or implementation monitoring.- Prescriptions, guidelines, or BMPs must be properly implemented if soil disturbance standards are to be met.

The USDA Forest Service through periodic program reviews, ensures that soil conservation measures called for in environmental disclosure documents (Environmental Impact Statements and Environmental Analysis) are included as contract requirements. Contract administrators are responsible for ensuring these requirements are properly implemented. Because local application and interpretation of these practices can vary, comparisons of results between geographic areas are sometimes weak.

In British Columbia, all silvicultural prescriptions (per the Forest Practices Code Act) and all Site Plans (per the Forest and Range Practices Act) are legally required to have soil disturbance objectives based on analysis of local soil and site conditions. It is the responsibility of the licensee to set applicable soil disturbance standards, based on the Ministry's protocol for predicting soil sensitivity to degrading processes, such as compaction. The licensee is also responsible for ensuring their practices meet these site-specific standards. The Ministry is responsible for compliance monitoring.

In the US, some forest products companies, such as Weyerhaeuser, have developed internal requirements (standards) to ensure that soil disturbance does not exceed limits that would significantly reduce regeneration success, soil productivity potential, or water quality (Heninger 2003). Because Weyerhaeuser Company's soil-disturbance standards are based on a research database, validation monitoring is focused on filling some data gaps. BMPs designed to limit detrimental soil disturbance have been developed for ground-based harvesting and these BMPs are periodically reviewed with harvest managers and contractors. Various monitoring and environmental management processes are used to ensure that forest practices meet regulatory compliance and Company standards.

Operational or effectiveness monitoring.- A number of public land management agencies and some industrial forest landowners in the Pacific Northwest have implemented soil disturbance monitoring protocols to determine if current prescriptions and BMPs meet soil-disturbance standards. Although disparity exists among the protocols used, there is a trend toward uniformity and information sharing.

The USDA Forest Service, Pacific Northwest Region, developed and implemented provisional soil-disturbance standards in 1977. Some criteria for determining detrimental soil disturbance were based on quantitative sampling and laboratory analysis rather than visually discernable, qualitative criteria. Acceptable limits for these properties were based on a few available publications rather than from replicated studies conducted on the major soils in question. To obtain reliable estimates of soil disturbance based on these quantitative and visual criteria, a sampling system utilizing a series of randomly oriented line transects was developed (Howes et al. 1983). This sampling method yielded reliable information but was costly to use and did not facilitate clear communication among land managers. As a result, the amount of operational (effectiveness) monitoring declined to almost nil. This prompted the search for monitoring protocols based on qualitative or visual soil disturbance categories. In addition, it was recognized that validation of both quantitative and qualitative standards was essential.

Weyerhaeuser in the Pacific Northwest also uses random line-transects, originating from a systematic sample of points. The design has a predetermined random starting point and a randomly oriented square grid. The sample unit is a 100-foot (30.5 m) transect that radiates from the sample point at a randomly selected azimuth. The amount of soil disturbance by visual classes is estimated by measuring the corresponding distances of undisturbed and disturbed soil intersected by the line transect. The proportion of transects with undisturbed and disturbed soil is estimated for each transect and then descriptive statistics of disturbance types are calculated from the combined samples. Sample size (number of transects) is based on expected variability in soil disturbance and designed to be large enough to achieve a specified margin of error and confidence. The point/line-intercept sampling method is preferred because it tends to be

independent of harvest patterns (low risk of bias from sample being coincident with systematic patterns of soil disturbance), and it gives a suitable approximation of population variance.

In British Columbia, operational (compliance) and effectiveness monitoring utilizes the standard soil disturbance protocol (Soil Conservation Surveys Guidebook; B.C. Min. Forests 2001) which was originally based on a modification of Howes et al. (1983). For in-block disturbance on smaller, and soon all, cutblocks, this system now uses point- intercept sampling along parallel transects, encorporating binomial distribution analysis of confidence limits. For permanent access structures (roads, landings), the system utilizes length and width measurements; currently, use of satellite imagery or air photos for estimating road area is being assessed. Moreover, during recent effectiveness evaluations (piloted in 2003 by B.C. Forest Practices Board, and in 2004 at the operational level), a series of questions were asked of the auditors, such as "does the level of permanent access appear to be the least required to access the timber?". Further effectiveness evaluation will be undertaken by the Ministry under its stewardship mandate.

Recommendations

We suggest that forest soil scientists develop close working relationships regionally to address the following opportunities: (1) documenting existing databases and determining what is needed to assess impacts of typical disturbance patterns on tree growth or other important ecological functions, (2) developing easy-to-use soil disturbance classifications and monitoring methods to assess levels of detrimental disturbance.

Validation/Strategic database.- More research is needed to develop cause-and-effect relationships between disturbance and (1) soil productive capacity, (2) soil resilience (recovery rates), and (3) hydrologic response (erosion, runoff, infiltration, water-holding capacity) for a wide variety of soils.

Results of such studies must contribute to strategic databases that document types and severity of soil disturbance that affect site productivity and hydrologic response. This information must be accessible to all concerned with soil disturbance effects to enable evolution of standards and practices.

Operational or Effectiveness Monitoring.- A critical review of methods for monitoring or assessing soil disturbance is needed. Advantages and disadvantages of various methods should be identified and several alternatives developed to fit specified objectives, sampling accuracy, and risk tolerance. The desired outcome is a consensus on a visual classification system and several optional methods for monitoring disturbance, but without identifying a single best method. A reliable soil disturbance assessment or monitoring protocol should address sampling considerations detailed in Curran et al. (200x). These include selecting a representative sample of the activity area, and securing reliable and meaningful data with the least investment.

Note that in an ideal world, an extensive strategic database that documents cause and effects of soil disturbance should exist before setting standards that define detrimental disturbance. Although implementing standards that are not validated is undesirable, many in both government and industry recognize that public and market pressures force us to implement policies and practices based on best available information albeit weak. We urge a general recognition that validation is lagging and that information is needed to minimize the consequences of either unnecessary or inadequate restrictions.

Section C. Reliable methods to rate soils for risk of soil disturbance

Forest soils differ in their physical properties and topographic-climatic settings. These differences strongly determine the reaction of individual soil series or phases to heavy equipment used to harvest trees and to prepare sites for regeneration. Risk, in a classical engineering sense is a function of the inherent hazard and the consequence of that occurrence. For example, the hazard may be a soil's inherent erodibility while the consequence is the on-site effects on productivity

and the off-site effects on sedimentation. Pedological principles about soil development and occurrence on the landscape can provide a framework for organizing and communicating knowledge about soil hazard or risk. The knowledge being extrapolated and applied comes from several sources: application of first principles, monitoring, empirical relationships, practical experience, and other anecdotal observations. Such knowledge can be used to create soil risk ratings.

Current status, and what is needed

As used in Northwest U.S.A., risk ratings are predictions of a soil's resistance to a degrading process (e.g., compaction, rutting, displacement) resulting from a specific activity under particular conditions. Rating soils for their anticipated changes in properties (e.g., soil density and structure) and subsequent processes (e.g., water infiltration, air exchange, water storage) can provide a useful means (interpretation) for avoiding, reducing, or mitigating potential negative effects of heavy equipment on soil properties and subsequent functions. By knowing the relative risk for individual soil (mapping) units, one can appropriately prescribe mitigative measures for those soils that are at most risk. Rating soil resistance to traffic however, is an intermediate step toward our ultimate goal of predicting practical consequences of changed soil properties for vegetative growth, soil loss, and subsequent off-site sedimentation.

Rating soils for their relative resistance to soil disturbances (initial response) and resilience (subsequent recovery) is an example of "risk analysis in adaptive management". In this risk analysis, one: (1) lists possible outcomes, (2) estimates their likelihood under one or more alternative future scenarios, and (3) calculates their individual utilities by weighting outcome likelihood by outcome values (Marcot 1997). This procedure of weighting by outcome value helps managers (decision-makers) determine the overall risk of a management action. In our case, the outcome value is maintaining or improving soil productive capacity.

Applying risk analysis to forest soils thus requires knowledge to respond to several decisions: (1) What are the possible outcomes of operating heavy equipment on forest soils

(e.g., is the soil compacted, puddled, displaced)? (2) Under what conditions are these outcomes likely to occur? For example, we suspect these effects are more likely when soils are wet or moist when textures are clayey not sandy soils, and when ground-based equipment rather than cable systems are used for logging. (3) What are the practical consequences of the resulting disturbance for soil productive capacity as indicated by tree growth?

The prevailing opinion is that severe or extensive soil disturbance is likely to reduce tree growth and increase erosion and off-site movement of sediments. Research, however, indicates that overall risk of using heavy equipment to soil productivity can range from negative to positive.

Our current knowledge is insufficient to rate directly overall risk (e.g., to sustainable forestry) of using heavy equipment at specified sites. We can instead respond to decision 2 (likelihood of outcome under future scenarios), by rating soils for their relative resistance to change when mechanically impacted at worst-case conditions: soil moisture conditions are unfavorable (wet, moist, non-frozen) and practices are not mitigated by appropriate equipment and operator techniques. Such risk ratings alert planners to prescribe extra care and mitigative measures for the most sensitive soils to reduce likelihood of extensive soil damage. Equally important, risk ratings alert planners to reduce mitigative efforts and costs on least sensitive soils. Although we believe that our current knowledge of the practical consequences of soil disturbance for tree growth is limited and variable, we suspect that our knowledge of on-site hydrologic effects is even more uncertain.

In the U.S.A., soil risk-ratings (interpretations) are normally based on descriptive information for each mapping unit identified in detailed soil surveys. By various means, soil mapping units are rated for their susceptibility to a degrading process. Wherever risk ratings are based on soil maps, actual on-site soil conditions must be verified. In the absence of detailed soil mapping and classification, interpretations can be made for specific sites based on their observed characteristics.

Ratings or interpretations as produced in the USA by the Natural Resources Conservation Service (NRCS) and by Weyerhaeuser Company in western Washington and Oregon are based on modal characteristics of individual soil series and on associated site factors.

In the USA, the best source of data for soil interpretations is the National Soils Information System (NASIS), which is the official database of the National Cooperative Soils Survey. These data result from surveys of forest and agricultural land in individual counties or project areas. The NRCS uses these data to provide various interpretations for individual soils in these survey areas. Similarly, the Canadian Soil Information System (CanSIS) provides a compilation of data from individual soil surveys in that country.

Weyerhaeuser Company rates the relative susceptibility of soil mapping units to severe disturbance based largely on soil physical properties (Heninger et al. 1999, Scott et al. 1998). Soils are ranked on the basis of the ease with which severe soil disturbance (classes 3, 4, and 5) can occur from ground-based machine operation. Soils are assigned to one of five risk classes (Table 1). Risk ratings for some soils mapped in one tree farm are displayed in Table 2.

In the absence of detailed soil surveys, on-site assessments are necessary. Representative data from project areas are evaluated with decision-logic tables or binomial keys. For example to guide forest practices in British Columbia (Forest Practices Codes 1995), five soil disturbance hazards were defined and interpretive guides prepared for field assessments (B.C. Ministries of Forests and B.C. Environment 1995).

With or without soil mapping data, soil risk ratings can integrate current knowledge for forest planning and operations. For example, harvest setting maps can include the soil operability rating of major soils within the setting. In British Columbia, maps might show an integrated soil sensitivity rating based on one or more hazards. Such maps alert harvesters about: the amount of care needed to avoid excessive soil disturbance, when to schedule operations, and what portions of the setting are most or least operable in wet weather. Mitigative measures for harvesting were discussed for conditions in western Washington and Oregon (Heninger et al. 1997) and for Interior British Columbia (Curran 1999).

Current methods for rating soils could be improved. For example:

1. Use existing quantitative data from past soil-disturbance monitoring to validate or calibrate existing rating systems.

2. Validate current predictions of risk to soil properties or processes by conducting post-activity monitoring; was, for example, a high risk rating substantiated?
3. Validate predictions of impacts on tree or vegetative performance or erosion that are implied in risk ratings. E.g., where and what "detrimental" soil disturbance is really detrimental to tree growth?
4. Expedite feed-back and continuous improvement of risk ratings, prescriptions, and operational practices (BMPs).
5. Compare and align regional approaches for rating and protecting soil.

Progress

- The NRCS currently has an active committee to evaluate which forestry interpretations are useful and how these can be improved.
- Several organizations are improving existing rating systems that are either applied to specified mapping units or used for on-site field evaluations of soil resistance or resilience to equipment traffic. Revisions include:
  1. Using principles of soil science and qualitative observations (expert opinion).
  2. Utilizing quantitative data from past monitoring of soil disturbance to calibrate decision rules (B.C. Ministry of Forests, USFS Pacific Northwest Region and Weyerhaeuser Co.). After a predictive model is developed, a computer program will assign risk classes to soil series or phases based on an algorithm that uses their modal characteristics and site factors.
  3. Validating predicted risk to soil properties by monitoring after ground-based operations (B.C. Ministry of Forests, Weyerhaeuser Co. in the western Washington and Oregon).
  4. Validating implied predictions about tree performance by measuring tree survival and growth over a range of soil disturbances (B.C. Ministry of Forests, Weyerhaeuser Co.).

Recommendations

- Forestland and individual cutblock areas should be stratified to designate portions requiring either unique or similar prescriptions and mitigative measures. Portions judged to have low risk for specified activities justify more flexible prescriptions and less expenditures for mitigative measures. Conversely, high-risk soils require more attention, mitigation, and research.
- Risk ratings and reliable supportive data should be continuously documented and displayed on maps and GIS layers to integrate data, experience, and knowledge. Soil maps and guidelines are useful tools for field personnel who may be less experienced or knowledgeable about soils. We encourage detailed soil mapping (1:24,000 scale or larger) and representative descriptive data for each mapping unit. On-site inspections are still needed to confirm accuracy of the mapping and the actual on-site characteristics. In the absence of detailed soil mapping, each area proposed for harvest requires reliable soil assessment as part of planning and prescription (e.g., methods described in Curran et al. 2000).
- The accuracy of current risk-ratings should be validated by measuring the effects of operational practices on soil characteristics and, more importantly, on tree growth and erosion that increases in stream sediments. Results of this validation monitoring may warrant changes in rating systems, standards and guidelines, and monitoring procedures.

Summary / Conclusions

A more uniform and coordinated approach to soil disturbance is needed. This approach will clarify and support development and reporting of indicators of sustainable forestry, such as those outlined in the Montreal Process (MP). In this paper, we discussed recent regional progress

in northwestern North America, on three topics that facilitate reporting under various sustainability protocols: (1) common terms and comparable guidelines for soil disturbance, (2) cost-effective and statistically sound techniques for monitoring and assessing soil disturbance, and (3) improved methods to rate soils for risk of detrimental soil disturbance.

To accelerate progress at the regional scale, we require synthesis of regional data about soil disturbance, tree growth, and hydrologic response. Assembling information in a workable database will facilitate tracking and relating ecosystem response to practical indices of sustainability. Also at the national and international levels, we need to pursue correlation and commonality in disturbance terms and practical standards. At all scales, we need to develop a reliable and adaptive process (continuous improvement) for monitoring and managing soil disturbance and its effects on site productivity. Components for this process were discussed by Curran et al. (200x), and Terry et al. (200x).

We think the process and its components are critical for achieving the desired outcomes (Figure 2). Although we report progress on several of those components, we believe that quantifying and documenting the consequences of soil disturbance for forest growth in regional databases is paramount. Regional databases should document consequences and the activity-soil-site conditions where these consequences were measured. With such databases, we can better understand and predict the practical consequences of management practices and soil disturbance. Moreover, we can more efficiently contribute to continuous improvement of BMPs, training, and guidelines. Although the Montreal Process seeks to ensure sustainable forestry, the MP specifies the "desired outcome" without specifying the process and components required to attain that outcome. We strongly recommend soil scientists help develop the process and critically review results reported to the Montreal Process by Technical Advisory Committees (TACs) and the USFS Forest Inventory and Assessment Group (FAI).

Literature Cited

B.C. Ministries of Forests and B.C. Environment, 1995. Hazard assessment keys for evaluating site sensitivity to soil degrading processes guidebook, June, 1995. Forest Practices Code of British Columbia. Victoria, B.C., 24 pp. Latest version: http://www.for.gov.bc.ca/tasb/legsregs/fpc/FPCGUIDE/HAZARD/HazardAssessKeys-web.pdf [Accessed December 2004]

B.C. Ministries of Forests. 2001. Soil conservation surveys guidebook. 2nd ed. For. Prac. Br., B.C. Min. For., Victoria, B.C. Forest Practices Code of British Columbia Guidebook. 63 pp. http://www.for.gov.bc.ca/tasb/legsregs/fpc/FPCGUIDE/SOILSURV/soilconsurv.pdf [Accessed December 2004]

CCFM, 2003. Canadian Council of Forest Ministers. Defining sustainable forest management in Canada. Criteria and indicators. 2003. http://www.ccfm.org/2000pdf/CI_Booklet_e.pdf [Accessed November 2003].

Curran, M. 1999. Harvest systems and strategies to reduce soil and regeneration impacts and costs. *In*: Impact of machine traffic on soil and regeneration. Proceedings of FERIC's Machine Traffic/Soil Interaction Workshop held at Edmonton Alberta, Feb. 1999. FERIC Special Report No. SR-133. pp. 75-11.

Curran M., and D. Maynard 200x. Tree growth on disturbed calcareous forest soils in southeastern B.C. Paper presented at: Conference on Long-term Productivity of Forest Soils, Alexandria, Louisiana, 17-19, Oct. 2000.

Curran, M., Davis, I. and Mitchell, B. 2000. Silviculture prescription data collection field handbook: Interpretive guide for data collection, site stratification, and sensitivity evaluation for silviculture prescriptions. B.C. Min. Forests Land Management Handbook No. 47, 156 pp. Includes *forms FS39A and B* http://www.for.gov.bc.ca/hfd/pubs/Docs/Lmh/Lmh47.htm [Accessed December 2004]

Curran, M. D. Maynard, R. Heninger, T. Terry, S. Howes, D. Stone, T. Niemann, and R.E. Miller. 200x. A strategy for more uniform assessment and reporting of soil disturbance for

operations, research, and sustainability protocols. Discussion paper from: Conference on Long-term Productivity of Forest Soils, Alexandria, Louisiana, 17-19, Oct. 2000

Froehlich, H. A. and D.H. McNabb. 1984. Minimizing soil compaction in Pacific Northwest forests. p. 159-192. In: E.L. Stone (ed.) Forest Soils and Treatment Impacts. Proc. 6th North American Forest Soils Conf. Soil Sci. Soc. Am., Madison, WI.

Gomez, A., R.F. Powers, M.J. Singer, and W.R. Horwath. 2002. Soil compaction effects on growth of young ponderosa pine following litter removal in California's Sierra Nevada. Soil Sci. Soc. Am. J. 66:1334-1343.

Heninger, R. 2003. Western Timberlands - Forest Management Standards – Soil Disturbance / Ground-Based Harvest. Weyerhaeuser internal document. 7pp.

Heninger, R.L., Terry, T., Dobkowski, A., and Scott, W. 1997. Managing for sustainable site productivity: Weyerhaeuser's forestry perspective. Biomass and Bioenergy. 13(4/5):255-267.

Heninger, R. L., Scott, W., Miller, R. E. and Anderson, H. 1999. Updated: Oregon operating areas: soil operability ratings for ground-based logging and site preparation equipment. Internal Report, Forestry Research Technical Report 055-3110-02, Weyerhaeuser Co., Tacoma, WA.

Howes, S., J. Hazard and J.M. Geist. 1983. Guidelines for sampling some physical conditions of surface soils. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. R6-RWM-146-1983. 34 p.

Marcot, B. 1987. Testing your knowledge base. AI Expert 2: 42-47.

Miller, R.E., W. Scott and J.W. Hazard. 1996. Soil compaction and conifer growth after tractor yarding at three coastal Washington locations. Can. J. For. Res. 26:225-236.

Minore, D. 1968. Effects of artificial flooding on seedling survival and growth of six northwestern tree species. USDA Forest Service Research Note PNW-92.

Montréal Process Working Group, 1997. First approximation report on the Montréal Process, 1997. The Montréal Process Liaison Office, Canadian Forest Service, Ottawa, ON.

Powers, R.F.; Alban, D.H.; Miller, R.E.; Tiarks, A.E.; Wells, C.G.; Avers, P.E.; Cline, R.G.; Fitzgerald, R.O.; Loftus, N.S., Jr.; 1990. Sustaining site productivity in North American forests: problems and prospects. In: Gessel, S.P.; Lacate, D.S.; Weetman, G.F.; Powers, R.F., (Eds.) Sustained Productivity of Forest Soils, Proceedings of the 7th North American Forest Soils Conference. Faculty of Forestry, Univ. British Columbia, Vancouver, B.C., pp. 49-79.

Salafsky, N., and Margoluis, R. 2003. What conservation can learn from other fields about monitoring and evaluation? BioScience 53: 120-121.

Scott, W. 2000. A soil disturbance classification system. Internal Report For. Res. Tech. Note, Paper #00-1, Weyerhauser Co., Federal Way, WA. 12 pp.

Scott, W. Dobkowski, A., Heninger, R., Miller, R. and Anderson, H.. 1998. Washington operating aeas: Soil operability ratings for ground-based logging and site preparation equipment. Weyerhaeuser Co. Forestry Research Technical Report 055-3110-1. Federal Way, WA.

USDA Forest Service. 2003. National report on sustainable forests – 2003. United States Department of Agriculture Forest Service FS-766, October 2003 (Draft). http://www.fs.fed.us/research/sustain/ [accessed November, 2003].

Table 1: The general logic currently used by Weyerhaeuser Co. to classify soils in western Washington and Oregon

	Soil Operability Risk Class				
Soil Property	Low	Moderate	High	Very High	Saturation
Topsoil depth	Very deep	Deep	Moderate	Shallow	Shallow
Moisture movement	Rapid	Moderate	Slow	Very slow	Very slow
Texture	Sandy	Loamy	Clayey	Clayey	Clayey
Depth to water table	Very deep	Deep	Moderate	Shallow	Very shallow

1 Table 2. Risk Ratings for five mapped soils in a Weyerhaeuser tree farm in Oregon.

2

Soil Series	Topsoil depth (cm)	Topsoil texture	Topsoil permeability	Subsoil texture	Subsoil permeability	Water table depth (m)	Risk rating
Bellpine	15	Silty clay loam	Moderate	Silty clay	Slow	1.8	Very high
Blachly	64	Clay loam	Moderate	Silty clay	Moderate	1.8	High
Digger	28	Very gravelly loam	Fast	Very gravelly loam	Fast	1.8	Low
Hazelair	28	Silty clay loam	Moderate	Silty clay	Moderate	0.4	Saturated
Kinney	36	Gravelly loam	Moderate	Clay loam	Moderate	1.8	Moderate

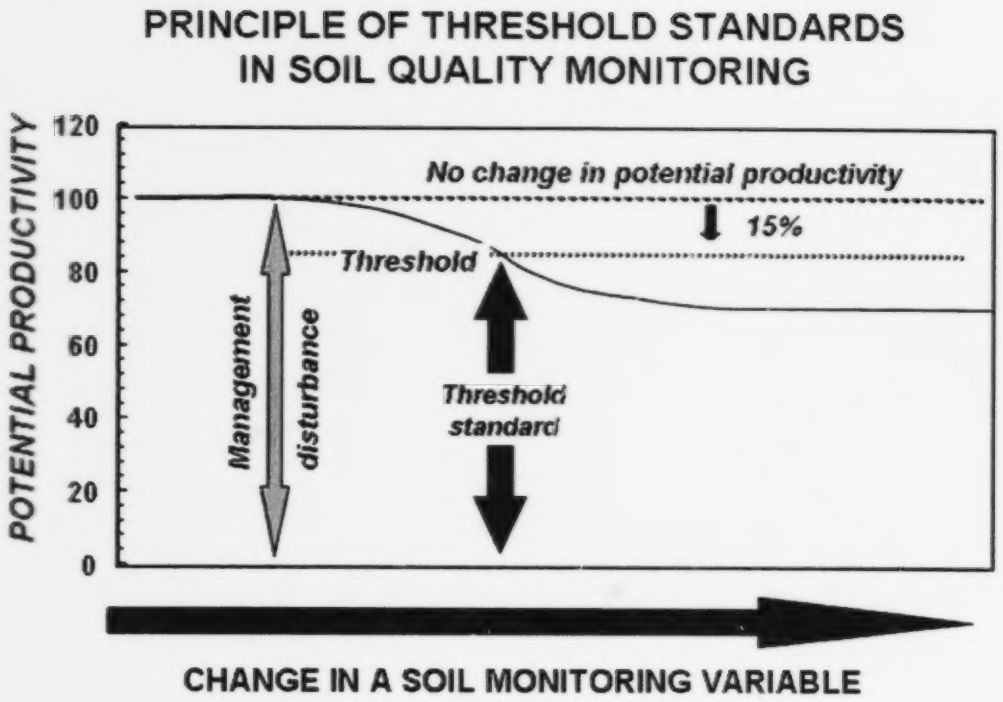

Figure 1.— Hypothetical relationship between an effective soil quality monitoring variable and a site's productive potential as envisioned by the USDA Forest Service. After detrimental soil disturbance, potential productivity declines. The change in the soil-monitoring variable that could result in a 15% or more decline in potential productivity is defined as the threshold standard.

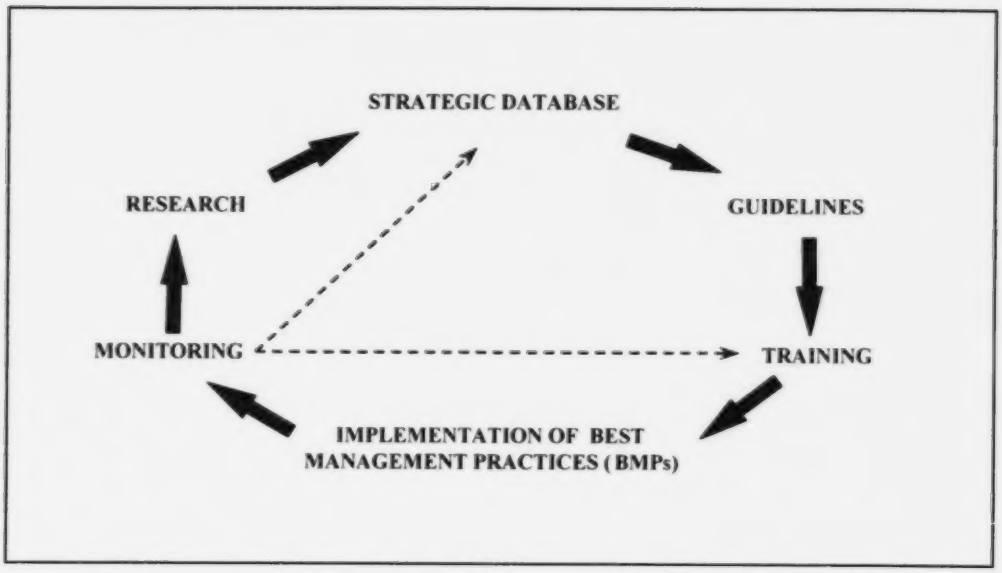

Figure 2.— Process components required to achieve sustainable site productivity.